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Nanotechnology and Synthetic Biology: The Ambiguity of the Nano-Bio Convergence

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Résumé : Cet article étudie l'étendue de la convergence réelle entre les nanotechnologies et la biologie de synthèse, symbole des technosciences biologiques. Pour traiter la question de la dichotomie entre le niveau des objets auquel on observe un processus de pluralisation plutôt qu'une convergence, et le niveau des discours, où le scénario de la convergence semble rester l'explication dominante, nous développons une analyse des disciplines comme dispositifs au sens de Foucault. Cela permet de décrire précisément les différentes strates composant les dispositifs et leurs dynamiques. La convergence des Nanotechnologies, des Biotechnologies, des technologies de l'Information et des sciences Cognitives (convergence NBIC) apparaît alors comme l'interprétation réductrice d'un contexte scientifique et technologique complexe.

Abstract: This article studies the extent of the concrete convergence between nanotechnology and synthetic biology, emblematic of the biological technosciences. To address the issue of the dichotomy between the level of the objects, where we observe a pluralization process more than a convergence, and the level of the discourses, where the convergence scenario seems to remain the dominant one, we develop an analysis of the disciplines as apparatuses ("*dispositifs*") in Foucault's sense. This enables a precise description of the different strata composing the apparatuses, and of their dynamics. The convergence of Nanotechnology, Biotechnology, Information technology and Cognitive science (NBIC convergence) then appears as a simplified interpretation of a complex scientific and technological context.

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1 Introduction

Fifteen years after Roco's & Bainbridge's foundational report on the convergence of Nanotechnology, Biotechnology, Information technology and Cognitive science (NBIC convergence) [Roco & Bainbridge 2003], we may start assessing to what extent these scientific and technological fields are effectively converging. In 2003, when the report was released, most of the fields were considered emergent, and the convergence was thus a projection based on potential developments and on clues about the direction of these developments. Fifteen years later, even if the developments of the different disciplines were slower than predicted, we have sufficient elements to confront the scenario of the convergence of the emerging technologies with the reality of what is happening. We will focus, in this article, on the convergence of nanotechnology and biotechnology.

When it was proposed in 2003, the NBIC convergence was not formulated based on any observable reality. It was a projection of current tendencies and potentials into the future. Furthermore, it was an ideological program, putting forward the utopian vision of "a fantastic new wave of innovations" [Est, Stemerding *et al.* 2014, 13] leading automatically to the "improvement of human performance" [Roco & Bainbridge 2003, ix]. Guchet underlines the two presuppositions of this program [Guchet 2014, 166]: first, the sciences and technologies taking part in this convergence are only considered through the applications they will be able to deliver, and second, it is possible to mobilise an entire society towards one ultimate goal—in this case developing applications that improve human performance. Thus, the NBIC convergence is not another term for interdisciplinarity or for the usual process of the integration of technology, it is a transhuman utopia based on capitalism: in the framework given by Roco & Bainbridge, the ultimate meaning and direction of the convergence is to be found in ideology.

The epistemological translation of the transhumanist program is the idea that matter manipulation at the nanoscale (i.e., manipulation of atoms, molecules or groups of them) will give birth to a transdisciplinary technoscientific culture. In this article, we will investigate the reality of such an epistemological culture, and ask if there is a convergence of the sciences and technologies beyond this kind of ideological reconstruction. To answer this question, we will focus on the methods and objects of the different disciplines, as well as on their epistemic cultures.

2 Apparatus analysis

Xavier Guchet explains that it is possible to take a step aside from the ideological program of the NBIC convergence to understand what is really at work within the field of nanotechnology. According to this analysis, nanotechnology is not so much a convergence as a "proliferation, a pluralisation of the strategies of intervention on matter[1]" [Guchet 2014, 167]. This observation is largely valid for the other dimensions of the NBIC convergence as well, and especially for biotechnology. Nevertheless, merely presenting the pluralisation process at work leaves us with no possibility for discussing the idea of the NBIC *convergence*. To avoid this conceptual trap, Guchet proposes talking about apparatus (*dispositif*, in the sense given by Deleuze to Foucault's concept) [Guchet 2014, 169]. As an apparatus is composed of heterogeneous elements (from discourses or social entities to concrete technical objects), it integrates both the concrete scientific and technical reality and the values mobilized by the actors. For Guchet, the major advantage of this concept is that it unites the process of organisation ("territorialization", "stratification") and the resistance to this process, or the tendency towards another organisation ("deterritorialization", "line of flight")[2]; it unites the actuality, even the materiality of a discipline, and the potentiality still contained in the field as well as in the concrete objects to develop into other directions (other scientific approaches, other modes of action on the world, etc.).

The question we should ask then is: to what extent is there a convergence between the NBIC apparatuses? The NBIC convergence program even postulated the realisation of an NBIC apparatus in the near future. Its foundation, its first stratum should now be observable, but leaving aside the transhumanist reactivation of the NBIC convergence discourse, very few scientific and technical results explicitly place themselves under the NBIC label. There may be, nonetheless, an underlying converging process in day-to-day scientific cultures and practices. We will investigate this hypothesis by focusing on the convergence between the nanotechnology apparatus and the biotechnology apparatus, and more precisely on the apparatus of synthetic biology.

Synthetic biology is indeed the perfect candidate for analysing the state of the convergence of biotechnology with nanotechnology. Synthetic biology was defined during the "Synthetic biology 1.0 conference" (SB 1.0) held in June 2004 at the Massachusetts' Institute of Technology (MIT). While, the conference did not refer to the NBIC convergence, it took place soon after the release of Roco & Bainbridge's report. Moreover, the conference was held in the very "application oriented" context of MIT, and claimed that synthetic biology is both "scientific and engineering research" [Endy, Knight *et al.* 2004]. By its focus on applications, its research in computationally assisted rational design, and its claim that it will technically master life, synthetic biology—in

1. All translations are mine, unless otherwise indicated.

2. Territorialization and deterritorialization are two key-concepts developed by Deleuze & Guattari [Deleuze & Guattari 1980]. They express antagonistic dynamics, the first is a dynamic of organisation, or "stratification", the second of disorganisation, of creation of potential. But they are also circular dynamics, because any deterritorialization tends to stratify (either by reterritorializing or by creating a new stratum), while any stratum produces deterritorialization processes at its margins.

its MIT definition—displays a number of characteristics that qualify it as part of the NBIC convergence.

Moreover, as is the case for the other emergent scientific and technological fields of the early 2000s, synthetic biology (SB) can best be understood as a program, or an ambition rather than as a well-defined field. The presentation of SB 1.0 admits that the scientific and technical objectives ("to design and build biological parts, devices and integrated biological systems" [Endy, Knight *et al.* 2004]) need further technological support to be possible. Synthetic biology, as a discipline, structures itself around hypotheses and objectives, and not around a paradigmatic theory or shared methods. Bensaude-Vincent explains that the epistemic diversity in the discipline is possible because of an epistemic opportunism, grounded in a "hard-rock optimism", shared by the researchers promoting synthetic biology [Bensaude-Vincent 2013*a*]. The scientists engaged in synthetic biology never seem to be discouraged in their claims by negative results: they adapt and pursue their program. In consequence, synthetic biology has developed in many directions, encompassing research previously included in different disciplines (chemistry, genetic engineering, molecular biology, bioinformatics, etc.). Nevertheless, the organisation of synthetic biology is similar to that of traditional disciplines [Bensaude-Vincent 2013*b*, 122]: it is organised around specific journals and international conferences, it has its own academic courses and degrees, etc. The annual conferences (SB x.0) and the international Genetically Engineered Machines (iGEM) competition for students have done much for the international visibility and the rapid organisation of the discipline, as well as for the diffusion of epistemic optimism as a shared culture.

As with nanotechnology, which subsumed very diverse scientific and technological domains of research, synthetic biology is not reducible to any simple definition. It was indeed rapidly used as a label for many research programs, such as gene editing, gene regulation or gene deleting (all of which are now rather simply obtained with CRISPR-Cas9)[3] [Tremblay 2015], complete genome editing [Dymond & Boeke 2012], complete genome synthesis [Venter 2013], metabolic pathway engineering [Cameron, Bashor *et al.* 2014], [Del Vecchio 2015], as well as attempts at cell synthesis [Wu & Tan 2014] or research programs in xeno-genetics [Malyshev, Dhami *et al.* 2014], [Taylor, Pinheiro *et al.* 2014]. All these research programs do not have many aspects in common, save the recourse to strategies of synthesis. The concept of apparatus is therefore essential for expressing this special form of very tenuous unity (that is not thereby pure diversity either) and for encompassing a range of research objects as well as epistemic positions.

3. CRISPR-Cas9 is a molecular complex formed by a specific structure of ribonucleic acid (CRISPR meaning Clustered Regularly-Interspaced Short Palindromic Repeats), and by the Cas9 enzyme.

3 The convergence towards the molecular scale

Taking a step sideways from the programmatic stratum of the NBIC convergence, we would like to evaluate the concrete convergence of the apparatuses of nanotechnology and of synthetic biology, and, for this, our starting point will be at the level of objects. We now have fifteen years of experiments in the different fields that we can use to measure a potential overlapping of the research strategies and a potentially increasing intertwining of the objects. One of the claims of the NBIC convergence program is indeed the transversal manipulation of matter at the atomic level. In nanotechnology, this may mean quite literally moving atoms one at a time using a Scanning Tunneling Microscope (STM). Nevertheless, as Guchet demonstrates, scale is problematic even within the domain of nanotechnology and nanoscience [Guchet 2014, 38], and most of the experiments in nanotechnology as in synthetic biology involve a large number of atoms, in particular when dealing with proteins. Can we nevertheless identify converging capacities to act on matter? When we look at the two ends of the spectrum, action on matter in nanotechnology seems radically different from what it is in synthetic biology. Nanotechnology, as we pointed out, can move individual atoms with a STM, while synthetic biology can use the metabolic processes of bacteria or yeasts to assemble large fragments of synthetic DNA (tens of thousands of genetic base-pairs) via the very efficient homologous recombination processes of the cell [Venter 2013, 93], [Annaluru, Muller *et al.* 2014, 55].

The middle of the spectrum of scale might well be more useful for understanding why there may be a convergence, but the middle is located in the domain of neither physics nor biology, instead it concerns chemistry. The "nanomachines" of nanotechnology, as well as the molecular blocks (monomers) that constitute the polymers (proteins, ribonucleic acids (RNA), deoxyribonucleic acids (DNA), etc.) with which synthetic biology works, are molecules of the order of magnitude of the nanometre. Many experiments in nanoscience and nanotechnology take advantage of chemical dynamics to assemble artificial molecular structures that can then use a specific chemical reaction (or reaction cycle) to produce movement. The work of Jean-Pierre Sauvage, who shared the Nobel prize in chemistry in 2016, illustrates this: [2]catenane, for example, is composed of two intertwined rings that are assembled using the spatial organization property of a copper atom. Once assembled, one of the rings can move relative to the other using reduction-oxidation reactions [Sauvage 2017, 38]. Similarly, DNA and RNA are synthesized in vitro using a repeated four-step chemical protocol [Ma, Tang *et al.* 2012]. The technique on which synthetic biology is based is thus a form of nanotechnology, even if it is very rarely described this way, in the sense that it takes advantage of the assembling properties of chemical dynamics.

Chemistry can thus be seen as the real scale of the convergence, although this thesis would require a redefinition of the epistemological core of the NBIC convergence. While the NBIC convergence postulates a reductionist and atomistic approach centered on the idea of incremental engineering at the scale of the atom (as symbolised by the application of STM), Jean-Pierre Sauvage's chemically synthesised "nanomachines", as well as much of the synthesis and modification techniques used in synthetic biology, take advantage of the dynamics of quite complex chemical systems. This convergence is thus less a mastery over matter in a mechanical sense, and more a "patient negotiation" with the forces active at the nanoscale [Guchet 2014, 167].

Other techniques link, at the molecular level, atomic organisation of matter to biological applications, substantiating the convergence in its more usual sense. Microarrays are a good example of nanostructured materials used in a biological context. The microarray developed by the NanoBioSystèmes (NBS) group of the Laboratoire d'Analyse et d'Architecture des Systèmes (LAAS, CNRS, France) combines nanostructuring, molecular chemistry and optical properties of the system for biomedical diagnosis [Cau, Lalo *et al.* 2009]. The microarray itself is a glass slide on which nanogrooves of molecules, which serve as probes, are "printed". The idea is that the molecules to be detected in the biosample will attach themselves to the molecular probes. Once they are linked, the new molecular structure on the microarray modifies the way light is diffracted, thus enabling the diagnosis by simple optical observation. More generally, nanostructured surfaces are powerful and versatile tools for biology: they can serve not only for detection, but also for catalysis, or as a biomimetic surface for starting the synthesis of biomolecules or biomimetic molecular complexes.

Biomimetics is an important symbol of the nano-bio convergence, and provides ready arguments in favour of the NBIC convergence hypothesis. However, studying an example more closely leads us to qualify the storytelling behind the NBIC convergence. The NBS group of the LAAS developed a research program aimed at the synthesis of a molecular motor identical to the one in *E-coli*'s flagellum. It was a purely biomimetic approach but with important scientific and technological significance in nanotechnology, because it would have been a methodological proof of concept of the synthesis of a very complex biological structure. It would have been a significant step forward in the research on nano-engines as the motor in the flagellum is indeed a powerful source of mechanical work (at the cellular scale) that uses an electrochemical gradient to function. The experimental protocol uses surfaces with a nano-printed molecular layer mimicking the cell membrane [Chalmeau, Dagkessamanskaia *et al.* 2009]. The proteins, obtained through a biochemical reaction inside vesicle-bioreactors, auto-assemble on the surface as if on a cell membrane. Synthetic biology plays an important role in the experiment, while remaining quite separated: another laboratory, specialised in synthetic biology, delivered the materials (the proteins) that were assembled. This collaboration between nanotechnology and synthetic biology enabled the analysis of some aspects of the flagellar motor, but fell short of delivering the complete synthesis that was promised. A quick search of the literature seems to confirm that the project of a complete synthesis of such a complex protein structure remains excessively ambitious: scientists are still figuring out the structure and the mechanisms of such ensembles.

With this example, we see that there is a difference between what is announced at the programmatic level and what can actually be done in the laboratory: the "nanomotor" was never synthesised, the experiments just used the technical tools available to progress in the comprehension of a complex protein-based structure. While the research program put forward the application (the synthesis of a powerful nanomotor), the research results were in reality fundamental, and more significant as proofs of concept, on one hand for the use of protocell bioreactors, and on the other for the use of biomimetic nanosurfaces. It was thus a rather classic scientific program, closer to fundamental biochemistry than to nanotechnology. Moreover, it is difficult to call this collaboration between nanotechnology and synthetic biology a convergence in any strong sense, because there was neither a convergence of the research topics, nor a sharing of competences.

In contradiction with what the NBIC convergence suggests, beneath the surface of the general branding terms ("nano" or "synthetic biology") there is still a strong resistance from the traditional epistemic cultures. Despite diplomas in nanotechnology or in synthetic biology, the researchers still define themselves as molecular biologists, chemists, physicists, bioinformaticians, engineers, etc., who *do* nanotechnology or synthetic biology [Kastenhofer 2013, 133], [Klein 2010, 53]. The complexity of objects in these disciplines requires a level of specialisation from the scientists, engineers and technicians that is incompatible with a transdisciplinary professional identity. It is nonetheless possible to argue that the reason that interdisciplinary collaboration has become so frequent in contemporary science is because the "emergent" disciplines are converging, at least at the programmatic level. This (inter-) disciplinary paradox points to the complexity of the dynamics within and between the apparatuses in the nanosciences. We observe what we may call a "converging territorialization" at the programmatic level, producing examples of effective collaborations between laboratories from different disciplines, confirming the idea of the transdisciplinary value of epistemic optimism. But, at the same time, we observe a multiplication of objects, involving a plurality of scientific and technical skills, as well as a plurality of methods, strengthening the divergent territorialization of the more traditional disciplines.

4 Converging engineering ambitions

Following Bensaude-Vincent, who explains that the unity of synthetic biology has more to do with a general epistemic attitude than with any well-established paradigm, homogeneous objects or methods, we have to evaluate the epistemic dimension(s) of the nanotechnology and synthetic biology apparatus. The nano-bio convergence at the material level of the objects may indeed be ambiguous, but it might still be strongly driven by a shared perception of the world and of our modalities of action on it, forming a common epistemic background for the plurality of the research programs.

According to Guchet, the core epistemic attitude of the nanotechnology apparatus is defined by the ambition to invent and develop engineering modalities and processes at the nanoscale [Guchet 2014, 95], where classic engineering approaches are inoperative. It is thus a technology-oriented epistemic vision, grounded in the belief that engineering is possible at the nanoscale despite the quantic properties of matter, and especially its probabilistic behaviour (in opposition to the deterministic behaviour of matter at the macroscale). The hypothesis of bottom-up engineering—atom by atom—has proven difficult to implement concretely, but nanotechnology has invented more complex processes mixing bottom-up techniques (nano-structured surfaces for example) with top-down approaches (mimicking biochemical reactions, or using the auto-assembling properties of molecules). The idea of an opportunist epistemic attitude, requiring reasoning and imagination [Bensaude-Vincent 2013*a*], can thus be applied to nanotechnology as well as to synthetic biology.

Conversely, the engineering culture is not only characteristic of nanotechnology, it is also a prominent feature of some branches of synthetic biology. The engineering culture was determinant in structuring synthetic biology: its original distinction from the rest of biology was supported by scientists with engineering backgrounds (Drew Endy, Tom Knight, Robert Carlson, Roger Brent), who would even have preferred the more explicit name "intentional biology" [Campos 2010, 17]. A number of experiments seek to prove the pertinence of the analogy between cellular processes and micro-electronics, and between genetic regulation and computing. For example, in 2013, the implementation of several genetic logic-gates was reported: scientists managed to condition the expression of the gene coding for Green Fluorescent Protein (GFP) to the presence of two chemical inputs according to their logical relations (AND, OR, NOR) [Cameron, Bashor *et al.* 2014, 6]. In the same line of work, the title of an article is explicit concerning the computing and electronic analogy: "Robust multicellular computing using genetically encoded NOR gates and chemical 'wires'" [Tamsir, Tabor *et al.* 2010]. These examples give weight to the heuristic image of genetically *programming* a biological *chassis*.

Engineering also plays a more fundamental epistemological role in determining directions of research, such as the pursuit of modularity and orthogonality in genetic design. Modularity—usually illustrated by the image of Lego bricks—is typically a requirement of traditional engineering: it is indeed essential that the functional modules (in the case of synthetic biology, the genetic building blocks, such as genes and regulators) can be connected in the desired order, and universally recognised. The entire BioBrick program[4] developed around MIT and the iGEM competition is based on the modularity principle (BioBrick foundation). The orthogonality principle stipulates that independent modules should not have any effect on each other: put simply, one program should not change the execution of another. Once again, the computer analogy is very present. We have to note here that these two research orientations continue to encounter numerous obstacles [Vilanova, Tanner *et al.* 2015], [Del Vecchio 2015, 117], practical as well as theoretical, especially due to the chemical specificity of the different organisms, and due to Brownian chemical interactions in the cell. The chemical materiality of the genetic "software" interacts permanently with the non-universal cellular "hardware". Nevertheless, because of the epistemic optimism of synthetic biologists, the computer analogy remains a powerful intuition in the discipline.

The engineering epistemology is indubitably a force of convergence between the different apparatuses. It also clearly reflects the claim of the NBIC convergence that it will be possible to act, at both the atomic and the molecular levels, on life as well as on matter. This dynamic of convergence thus conveys a strong atomistic metaphysics in the field of biology. It is especially visible when considering the engineering strategies: modularity and orthogonality both require and produce atomistic interaction in the cell. These research strategies aim at breaking the concrete synergetic system of the cell down into independent, rationally designed building-blocks, in order to make the bottom-up engineering of life not only possible, but similar to the traditional engineering approach using mechanical parts. More generally, cells, in the field of industrial synthetic biology (including most of the genetic engineering), are considered abstractly as independent production units: a given cell must realise the entire metabolic process, and when the chemical transformation process is divided into several steps, these steps are usually distributed between different types of organisms, often separated into different milieux. The atomistic epistemology presiding over most engineering oriented branches of synthetic biology thus encompasses the regulation processes in the cell, as well as the cells themselves. This atomistic epistemology is reinforced by the classical use of "domesticated" yeasts and bacteria, which live well in homogeneous colonies, and consequently display less synergistic behaviours. By contrast, the studies of microbial life in natural environments give us a completely different picture of "normal" microbial existence and metabolic activity, in these contexts cooperation, specialization and continued association are very frequent [Dupré 2014, 221].

Engineering thus constitutes a force pushing towards strong converging territorialization, catalysing the epistemological program of the NBIC convergence to master nature from atoms to cells. Conversely, we have seen previously that the concrete scientific and technological results produce a pluralisation of the objects and of the modes of interaction with the

4. `https://biobricks.org/`.

forces of nature. All these processes induce contradictory dynamics in the epistemic dimensions of the apparatuses, because the pluralisation process has consequences on the theoretical models and on the implicit metaphysics behind the epistemic positions. While some proofs of concept in nanotechnology as in synthetic biology confirm the epistemic validity of atomist engineering of matter and of life, experimental failures and alternative strategies simultaneously support competing epistemic attitudes (emerging structures from complex interactions, ecological synergy, etc.) grounded in divergent metaphysical perspectives (emergentism, holism).

5 Epistemic metastability: a plurality of potential re-compositions

The apparatuses seem to be best understood as being in an ambivalent relationship to the NBIC convergence. Some strata are territorializing in the sense of a convergence, while other competing territorializations, as well as lines of flight, tend to produce a dynamics of divergence. Our analysis has enabled us to understand more precisely to what extent the nanotechnology apparatus and the synthetic biology apparatus converge, but we are no closer to understanding the general validity of the NBIC convergence theory.

For that, it is necessary to take another step aside and consider that the apparatuses are intrinsically under-determined. To put it differently, as they are constantly evolving, the description we make of these apparatuses is always partially inadequate, asynchronous. The NBIC convergence is one way to describe the apparatuses, but there are also other ways to make sense out of them. As they are intrinsically plural and proliferating, they hardly qualify as “normal science”, but neither abnormal nor in crisis. Using the concept of apparatus to describe nanotechnology or synthetic biology draws our attention to their own normality: being complex, dynamic, evolving, unpredictable, laden with potential. Simondon’s concept of metastability characterises such a state, where a system is, so to speak, more than one: metastability defines a system so saturated in potential and in internal tensions that a perturbation of the system would produce a transformation towards a new equilibrium [Simondon 2005, 26]. While metastability might be the normal state of the “emergent” sciences and technologies, it could also be a transition phase in science. From this perspective, the NBIC convergence appears as a strong performative reduction, a means to impose direction and meaning on the relative indeterminacy of contemporary science. Thus, it is important to reinstate the apparatuses in their plurality of open potentials.

The technical dimensions of both the nanotechnology and the synthetic biology apparatuses are clearly convergent, but the meaning of this convergence is still to be determined. As we have said previously, specific experiments in one field or the other may use elements produced by the other field: synthetic biology may be used to produce specific biomolecules for nanotechnological application, and nanotechnology may produce nanomaterials or nanosurfaces for synthetic biology to use as a catalyst, observation device, etc. The technical continuity is thus unquestionable, and constitutes a territorialization around the molecular scale common to both apparatuses. But, for now, the technical culture strata remain heterogeneous because of the specialization required to master these complex techniques. Even within the domain of synthetic biology, each modification technique, each model organism, almost each genetic design strategy requires a specific competence, and a dose of tinkering, of "kludging" [O'Malley 2009, 382], that participates in producing technical and scientific cultures specific to a laboratory and/or a team, sometimes even specific to a single researcher. The complexity of the technical protocols forces engineers and technicians to be highly specialised, thus rendering a transversal technical culture utopian.

In this context, the NBIC convergence program nonetheless postulates an actualisation of the epistemic uncertainty around transdisciplinary engineering, or in other words it anticipates the reinforcement of the territorialization dynamic. But the intrinsic diversity of the research programs in synthetic biology tends to oppose this program of convergence, especially because it opens numerous potentials for alternative territorializations. The recent and spectacular efficiency increase and cost decrease of genetic synthesis, genetic sequencing and genetic modification have indeed accelerated the externalization process of these technical aspects of synthetic biology: the technical manipulations are performed today by biology technicians and specialised bio-industries. While the existence of such industries confirms the convergent territorialization, the *externalization* of numerous technical aspects by the scientific laboratories acts as a competing deterritorialization process. Synthetic biologists, that have worked for around three decades to invent, perfect and master techniques enabling them to act on the genome, to read it and to reproduce it, can now focus on designing new experiments for "fundamental" research like, for example, using genetically modified cells to explore the spatial configuration of the genome, especially during specific phases of cellular development [Mercy, Mozziconacci *et al.* 2017], or on engineering metabolic processes of industrial or environmental interest. In other words, the more mature the technique is, the less important it is in the daily focus of the scientific fields. The technique stops being a research object in itself, and it becomes the background for action and for other research projects. The creation of new potential by the techniques thus opens up new development paths for the sciences, and contradicts the simplifying idea of a unidirectional convergence of the sciences and technologies.

The epistemological dimensions of the nanotechnology and synthetic biology apparatuses are also more contrasted than the NBIC convergence program would have us believe. There are in particular other territorialization tendencies, and other potential epistemic reconfigurations than those of the NBIC convergence. For example, synthetic biology is often associated with system biology. System biology can also be described as an emergent science, in the sense that it has developed rapidly following the increase of computational power, and especially the increased capacity to model complex systems, linked to the exponential capacity to collect huge amounts of biological data. The point of convergence between synthetic biology and system biology, justifying their institutional association, is the importance of modelling, and thus the central place of bioinformatics. Naïvely, system biology could be included in the NBIC convergence, as part of the bio-info convergence, but an interesting feature of system biology is its strongly analytical epistemic position [Kastenhofer 2013, 136]. From this perspective, then, the process of territorialization is very different from the one of NBIC: it is not driven by technical action goals, but by knowledge goals. Compared to the NBIC program, system biology represents a deterritorialization of the bioinformatics synergy towards complex interactions and interdependencies between the multiple levels of organisation inside the cell, and more generally in the living world. Dupré points out the renewed interest for the interactions between the organisms and the environment, notably through epigenetics, and for mutualistic collaborations and interdependency situations, as exemplified by the numerous studies of metagenomics about the microbiota—the microbial ecosystems that live in symbiosis with every macroscopic organism [Dupré 2014]. Dupré explains how this research profoundly transforms the paradigm of biology, from a theory structured by individual genetic identity and Darwinian selection (including competition for survival), to a theory structured by dynamic genetic interactions and vital interdependency [Dupré 2014, 203].

The pluralisation processes at the epistemological level present a challenge different from the pluralisation of the objects or even of the modes of action: how may a discipline—in this specific case, biology—continue to make sense as a whole, if its theories are pluralising? The picture of biology presented by metagenomics seems quite different from the picture presented by the engineering oriented branches of synthetic biology, yet they represent two possible developments of contemporary biology in convergence with other disciplines. The major difficulty in articulating the engineering oriented branches of synthetic biology and the branches of microbiology oriented towards complexity analysis is the divergent ontological furniture used in each field. On one hand, the biological entities are expressed in terms of atomistic technological elements (program, chassis, logic gates, regulation circuits, etc.), and on the other, these same entities are expressed in terms of holistic ecological parameters (chemical conditions of the milieu, messages, mutualistic interactions, etc.). To make sense of this ontological divergence resulting from the different dynamics at play in an apparatus, Quine's philosophy may be of help. Quine explains that the ontological furniture of a discipline, its system of objects, is relative to its particular system of word relations, i.e., its general theory [Quine 1969, 50]. Based on a holistic and pragmatic theory of language, the relativity of ontology to epistemology implies that translation is always possible between theories, on the express condition that it respects the relations organising the ontological system [Quine 1969, 50]. The possibility of translation explains why all epistemic positions included in a metastable epistemic system remain commensurable. In the example of contemporary biology, it would indeed be absurd to think that two sources of knowledge such as synthetic biology and metagenomics, or epigenetics, are oblivious of each other. There is knowledge circulation between these approaches, thanks to translation processes.

We can generalise this idea in considering all territorialization and deterritorialization processes in situations of epistemic metastability as consequences of translation choices. The NBIC convergence relies on translating the different ontologies in terms of mechanical engineering. One example in nanotechnology of this choice of translation is the description of the dynamic molecular structures as "machines" or "motors": most of the phenomena could just as well be described in terms of chemical reactions and configurations as in terms of the transformation of an energy impulsion into mechanical work. In the case of synthetic biology, the example of the "genetically engineered machine" (the "GEM" in iGEM) is similar: talking about implementing a genetic program in a biological chassis, sometimes even using the terms software and hardware, includes the objects of synthetic biology in the field of electronic and computational engineering, while it is also possible to talk about gene expression, metabolic functions, etc., and indeed these two forms of discourse coexist in the field of synthetic biology. As both the apparatuses are complex mixes of dynamics, some territorializing them as part of the NBIC convergence, others, on the contrary, opening deterritorializing potential, the NBIC convergence appears to be only one possible system of translation, indeed overlapping parts of both of them, but without exhausting the entire potential of either of them.

6 Conclusion

Evaluating the reality of the nano-bio convergence by comparing the nanotechnology apparatus and the synthetic biology apparatus enables us to see the NBIC convergence for what it is: one of the processes that the two apparatuses have in common. On one hand, the NBIC convergence is thus a powerful performative territorialization process, based on concretely converging technical and epistemic tendencies, and motivated by an ideological vision, on the other hand, it is only one way to make sense of the reality of the apparatuses by translating compatible variables and objects into the same discourse. The NBIC convergence, and more generally, the interpretation of the metastable state in which contemporary sciences and technologies are as a *convergence*, is a simplification. It presents the epistemic plurality and the proliferation of the modes of interaction with the world as a unidimensional dynamic. The pertinence of the idea of convergence is thus questionable, and since it clearly is an ideologically oriented program, it should be presented as such.

Another way to make sense out of this complexity is therefore to analyse the translation processes of ontologies that happen at the epistemic level, the knowledge circulation, the decompartmentalization of traditional disciplines, and the actual modes of existence of the objects and beings produced by the disciplines. As Guchet explains clearly in his study of nanotechnology, finding the right angle to make sense out of emergent technosciences is difficult, but it is an ethical necessity.

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